EIC Detector R&D Proprosal

The eRD108 Consortium

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Project Name: R&D on cylindrical and planar MPGDs towards an EIC detector

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1 Introduction

We propose R&D on three Micro-Pattern Gaseous Detectors (MPGDs) for the EIC project. These are applicable to all detector concepts, for which proposals are currently in preparation for a detector at the EIC. One type is the micro-Resistive-Well (μRWELL) detector, the second is the micromegas (MM) detector, and the third is the Gas Electron Multiplier (GEM) detector. Specifically, we propose to investigate

1. a single cylindrical μRWELL layer directly in front of the DIRC particle identification subdetector
2. several cylindrical MM detector layers to create a central barrel tracker
3. low-mass planar GEM/μRWELL detector layers for both electron and hadron end cap trackers.

We emphasize that our proposed R&D on cylindrical MPGDs targets two different applications for the two types of subdetectors. They are not to be considered interchangeable.

1.1 Risks addressed

The proposed R&D addresses various risks in the development of a Day-1 detector for the EIC project:

- Particle ID underperforms because reconstruction in DIRC and RICH devices suffer as the impact point and direction of the charged particle producing the Cerenkov radiation are not known precisely enough.
- Central track reconstruction based on Si detectors alone does not meet performance requirements on momentum resolution.
- The tracking acceptance and uniformity in the endcaps gets significantly compromised due to mechanical detector structures, support structures, and services.

1.2 Risk mitigation approach in proposed R&D

The μRWELL layer can improve the measurement of direction and impact position of charged particles that hit the DIRC by measuring a tracklet after the particles have traversed all material in the central tracker and its support structure. This information, that is little compromised by multiple scattering in material, can be used to seed the Cerenkov ring reconstruction in the DIRC. The goal is to measure the tracklet direction so that a directional resolution of 1 mrad or better can be achieved in combination with central tracking. This single μRWELL layer mainly targets the detector concepts with an all-Si design. It could be implemented in the ATHENA, CORE, and ECCE detector concepts. The R&D is necessary because nobody has yet constructed and operated a cylindrical μRWELL of any size to the best of our knowledge.

The MM detector layers aim at being a low-mass tracking detector that complements a silicon vertex tracker. A Si-MPGD hybrid design is currently under consideration for the ATHENA detector concept. The curved MM design will leverage the already existing low material budget CLAS12 MM technology, with the requirement that the detectors for EIC must have a 2D readout. The R&D will focus on the choice of the 2D readout patterns. In parallel, as the focus of the EIC are electromagnetic observables, lowering even further the material budget of MM detectors will be beneficial for the electron reconstruction. The focus of this R&D is to look for lighter materials for each component of the MM detector, starting with the materials used for the amplification mesh and the readout strips.

Low-mass planar GEM/μRWELL detector layers constitute the main tracking device in the intermediate pseudo-rapidity range of both electron and hadron end caps in the projective Si-MPGD hybrid design option for the ATHENA detector concept. ATHENA, CORE, and ECCE also feature very large planar MPGDs behind the RICH in the hadron end cap to aid RICH reconstruction. The proposed targeted R&D will leverage the successful earlier eRD6 effort to develop large low-mass GEMs. One focus will be to investigate smaller and stronger materials for the GEM frames in order to reduce the significant gaps in the endcap tracking acceptance due to these detector support structures. This concern recently emerged from simulations of the projective Si-MPGD hybrid tracker in the ATHENA hybrid detector concept. Another focus will be the development of a large planar trapezoidal μRWELL detector that could offer simpler and speedier construction and lower cost compared to a GEM detector.

2 μRWELL Layer for seeding DIRC reconstruction

2.1 R&D plan for FY22

We propose to design, build, and commission a functional small (20 cm diameter, 55 cm length) cylindrical μRWELL detector in FY22 and to test it in the proton beam at FNAL in FY23.

The main objectives are to demonstrate that a cylindrical μRWELL detector indeed works and to quantify its tracking performance. This μRWELL prototype will be equipped with a composite foil that integrates μRWELL amplification structure and capacitive charge-sharing readout as well as a 2D zigzag readout. These types of readouts can minimize the number of readout channels. Half of the detector will be read out with one of the structures and the other half with the other structure. The exact segmentation will be decided in the design phase.

The single-layer application allows us to move away from our earlier ultra-low-mass μRWELL design with all foils as needed for a full barrel tracker because this appears to be quite challenging to implement on a large scale as we learned from our previous R&D work with a mechanical all-foil mock-up. Instead, we propose to move to a design that uses thin rigid materials, e.g. carbon fiber prepreg material, to create a rigid but still low-mass inner main cylinder for the detector. The composite μRWELL/readout foil will be attached to the outside of this cylinder. The drift foil will be attached to the inside of another rigid outer cylinder. We will work to minimize the material for the drift electrode assembly because it is a critical design parameter as the charged particle to be tracked will be crossing this drift cylinder before hitting the DIRC. The amount of material located in the drift cylinder and in the inner cover of the DIRC determines how much multiple scattering the particle undergoes after being tracked in the cylindrical μRWELL and before hitting the active part of the DIRC. The material in the current design of the inner DIRC cover will inform the design and the choice of material for the drift cylinder. We will work with the DIRC R&D groups to optimize that.

On the electronics side, we propose to procure and commission an existing frontend & DAQ system, i.e. the VMM-SRS, that will allow us to read out the entire detector at the test beam with electronics that move beyond aging APV-based electronics. We do not plan to develop any new system based on a new or existing ASIC, but rather make use of an already developed system. We have investigated using the VMM based frontend and DAQ systems used by the Si-TGC detectors in the STAR forward upgrade and the CERN developed VMM-SRS. Ultimately we have decided to use the latter primarily because we already have a small scale VMM-SRS system in hand. Additionally as members of RD51, we will have access to VMM-SRS experts to aide in setting up and commissioning the system. In FY22 we will focus on gaining expertise and commissioning a small scale VMM-SRS system. In FY23, we will procure electronics needed to scale the frontend and DAQ system up so that the entire detector can be read out.

2.2 Person-power required and available for FY22

- Designer of composite μRWELL/readout foil - UVa graduate student (25% FTE, TBD) & BNL staff Alexander Kiselev (10% FTE, available)

- Designer of cylinder mechanics - FIT Ph.D. student Pietro Iapozzuto (75% FTE, available; the student has CAD experience from a previous mechanical design project for his MS thesis and will continue in the project beyond the design phase with construction and commissioning of the detector. We expect this to be an effective and (cost)-efficient approach compared with engaging temporary internal (BNL) or external (industry) engineering support.)
- Tester for electronics & DAQ - TU post-doc (50% FTE, TBD)
- Coordinators & Managers - Senior personnel from all institutions (unfunded)

2.3 Milestones and Timeline for FY22

- **Mechanical design completed (FIT)** - Date when BNL Funding Received (DBNLFR) + 4 months
- **Front-end electronics & DAQ design completed (TU)** - DBNLFR + 4 months
- **Readout foil design completed (UVa & BNL)** - DBNLFR + 5 months
- **Major Milestone:** Design completed - DBNLFR + 5 months
- **Mechanical assembly completed (FIT)** - Date when BNL Funding Received (DBNLFR) + 10 months
- **Existing (VMM-SRS) front-end electronics & DAQ tested (TU)** - DBNLFR + 10 months
- **Readout foil produced at CERN (UVa & BNL)** - DBNLFR + 10 months
- **Major Milestone:** Detector assembled - DBNLFR + 10 months
- **Integration of detector & electronics and benchtop testing** (All) - DBNLFR + 12 months
- **Major Milestone:** Detector ready for beam test - DBNLFR + 12 months

2.4 Preview of remaining R&D after FY22 until completion before FY24

The main task for FY23 will be to get the prototype ready for the beam test at FNAL, conduct the test there, and analyze the data afterwards. The group will conduct these tasks jointly.

3 Micromegas Barrel Tracker

3.1 R&D plan for FY22

Simulations performed for the EIC Yellow Report have shown that a 2D readout MM technology of similar implementation as the one in use in CLAS12 would meet the requirements for an EIC detector. However, any effort to reduce even further the material budget will be beneficial for the EIC physics program. Therefore, for FY22 we propose to focus on two main aspects: the optimisation of the 2D readout patterns and the reduction of material budget.

The main objective is to chose the MM 2D readout pattern that allows us to achieve the best resolutions while minimising the number of readout channels and the amount of copper in the active region. We plan to design and build small scale prototypes with 2D zigzag readout patterns as well as orthogonal strips. The 2D zigzag will allow the sharing of the charge over the two directions. The orthogonal strips will pickup the induced signal in the resistive layer. The sizes of the prototypes will be 400mm$\times$400mm for the zigzag and 100mm$\times$100mm for the orthogonal strips. The prototype readout material budget will be as close as possible to the one foreseen for the full size detector. We plan to produce separately the amplification Kapton layer (i.e. the layer with the resisitve paste bulked with a micromesh) and the readout foils and then press them together: this technique will allow us to test several combination of different resistive layers with different readout strip layouts. These detectors will be tested with cosmic rays, x-ray guns and, possibly, in beam tests.

With the goal of making MM detectors as light as possible, for the FY22 we plan to perform feasibility studies of using thin (5-25μm thick) foils of aluminum instead of the usual woven Inox mesh. The expected reduction of material budget for the aluminum mesh is about twenty times less then the Inox one. Holes of few micrometers will be created in aluminum foils through laser ablation. We have already identified a company able to perform such operations of laser ablation. We plan a few iterations of samples to check the reliability of the process. Once the final samples are selected, we plan to use these aluminum meshes with the bulk process. We also plan to investigate the use of strips on Al metalized Mylar as readout plane instead of the usual copper strips on Kapton. In FY22, we plan to search a industrial partner for the production of samples.

3.2 Milestones and timeline for FY22

- **Readout designs (Saclay & BNL)** - DBNLFR + 2 months
- **Readout foils received (Saclay & BNL)** - DBNLFR + 5 months
- **Bulk and assembly of prototypes (Saclay)** - DBNLFR + 7 months
- **Cosmic ray data taking completed (Saclay)** - DBNLFR + 8 months
- **Bench test with X-ray gun (BNL)** - DBNLFR + 10 months
- **Analysis and results (Saclay & BNL)** - DBNLFR + 12 months
- **Aluminum mesh received (Saclay)** - DBNLFR + 8 months
- **Bulking of aluminum mesh (Saclay)** - DBNLFR + 10 months

3.3 Preview of remaining R&D after FY22 until completion before FY24

The main task for the FY23 and FY24 will be to build one full scale curved MM tile (50 cm $\times$ 70 cm) with the final choice of the 2D readout. We plan to fully characterise the prototype with cosmic rays and in a beam test. The test beam can be carried out either at FNAL or in Europe (CERN or DESY).

For the very-low-material budget R&D, in FY23 we plan the procurement of Mylar foils with aluminium strips. The foils will be pressed together with a bulked amplification Kapton foil in small prototypes. We plan to characterise them with a ^{55}Fe source and in the cosmic ray test bench.

4 Planar GEM/μRWELL Endcap Tracker

4.1 R&D plan for FY22

While a fair bit of generic R&D for the low-mass MPGD endcap tracker has been completed within eRD6, the detectors cannot be considered “shovel-ready” for the EIC project. Several areas still need substantial targeted R&D.

A fully realistic simulation of the detector modules with detailed mechanics, electronics, support and services needs to be developed and integrated into GEANT4 simulations and into detector CAD files to inform the design. We propose to task a FIT graduate student who has started to work with the new DD4HEP simulation framework with this.

The frames of the current prototype modules are rather wide and would significantly reduce the acceptance of the endcap tracker in both ϕ and η if implemented in their current form. Since these frames are critical for maintaining the foil tension, reducing their size is a non-trivial task. Since the existing trapezoidal FIT prototype is constructed without glue, it can be reopened. FIT, UVa, and TU propose to jointly develop narrower frames and to test them in the existing prototypes and with mechanical mock-ups.

The 2D u-v readout structures tested so far have potential ghosting issues when the particle multiplicity in an event is high. A multilayer pad or strip-pad readout with capacitive sharing could get around that, but needs to be tested on a large module. This will be developed by UVa and deployed in a prototype.

Using μRWELL detectors instead of GEM detectors in the endcap can reduce mass, simplify construction, and potentially lower cost for the overall endcap tracker. However, nobody has built and tested a large trapezoidal μRWELL, yet, to the best of our knowledge. We propose that a prototype of such a detector be developed at UVa by Salina Ali, a UVa post doctoral research associate who has recently been awarded a 2021 JLAB EIC Post-doctoral Fellowship to work on MPGD technologies for EIC. She will be in charge of design, construction, and test of a planar μRWELL prototype.

4.2 Person-power required and available for FY22

- Simulation of realistic endcap detectors - FIT Ph.D. student Merrick Lavinsky (75% FTE, available)
- Planar μRWELL prototyping - UVa Post Doc. Salina Ali (50% FTE - JLab EIC Fellowship)
- Coordinators & Managers - Senior personnel from all institutions (unfunded)

4.3 Milestones and Timeline for FY22

- **Realistic endcap detector simulation completed (FIT)** - DBNLFR + 6 months
- **New frame designs completed (FIT & UVa & TU)** - DBNLFR + 5 months
- **Major Milestone: New frame designs tested (FIT & UVa & TU)** - DBNLFR + 12 months
- **Design of planar μRWELL prototype and procurement of the parts completed (UVa)** - DBNLFR + 9 months
- **Major Milestone: assembly and preliminary test of the prototype** - DBNLFR + 12 months

4.4 Preview of remaining R&D after FY22 until completion before FY24

The main task for FY23 will be to get the planar μRWELL prototype ready for the beam test at FNAL, conduct the test there together with the cylindrical μRWELL prototype, and analyze the data afterwards. The group will conduct these tasks jointly.

5 Suggested funding profile and funding split among the participating institutions for FY22 and FY23

Institution	FY22 request		FY23 request	
	Cylindrical	Planar	Cylindrical	Planar
BNL	\$30,000	-	\$15,000	-
FIT	\$53,602	\$12,314	\$53,602	\$38,391
UVa	\$35,640	\$14,600	\$23,760	\$23,760
Saclay	\$21,000	-	\$46,000	-
TU	\$56,063	-	\$92,063	-
TOTAL	\$210,905	\$26,914	\$254,185	\$62,151

In the case of university requests, fringe and indirect costs are included in the numbers in the table. A detailed breakdown of the request for each institution can be found in an excel sheet available at this link: Detailed Budget Breakdown (excel Sheet).